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Aquatic invertebrates along the progression of glacial and non-glacial streams in Matsch Valley (South Tyrol, Italy)

Abstract
Amongst other ecosystems threatened by climate change effects, living conditions in alpine streams in glaciated basins experience considerable changes as glaciers retreat, leading to changing structures of invertebrate populations inhabiting the riverbed. Community structures are monitored in Matsch Valley since 2014, but the species pool and population structures along the progression of the main Saldur stream and its non-glacial tributaries are not yet known. Moreover, most accurate and sensitive biotic metrics for the detection of long-term changes within benthic communities are not yet chosen. Here, we qualitatively analyze benthic communities from glacial and non-glacial reaches in the Matsch Valley along an altitudinal gradient (2252 to 980 m a.s.l.) and thereby provide a fundamental basis for the ongoing long-term monitoring of the Saldur stream. We show that the absolute number of chironomid taxa is higher at elevated stream reaches and that chironomids account for the majority of taxa in glacial streams, but are underrepresented in non-glacial tributaries. We emphasize that the ratio of chironomid taxa (or the subfamily Diamesinae, known to be adapted to 'glacial' conditions) compared to all present taxa might be a good indicator for environmental change related to glacial retreat and its effects on benthic communities in alpine streams.

Keywords: Saldur stream, altitude, Chironomidae, benthic ecology, species richness.

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Introduction
Aquatic invertebrates are dominating mountainous streams with high densities (e.g. Füreder et al. 2001, Lods-Crozet et al. 2001, Milner et al. 2001, Niedrist & Füreder 2016) and colonizing different types of water courses (e.g. of glacial and non-glacial origin). In alpine streams, these benthic organisms comply important ecosystem functions (Niedrist & Füreder 2017) and might even affect invertebrate populations further downstream (Wallace & Webster 1996), which are amongst others important food resources for fish populations in mountainous habitats. Generally, invertebrates – known to react sensitively to changes of environmental parameters (Lencioni & Rossaro 2005, Niedrist & Füreder 2016) – are used as indicators for changes in habitat conditions such as glacier retreat and other human influences (e.g. Khamis et al. 2014). Among all invertebrate groups, the family Chironomidae (Diptera: Chironomidae, also denoted as 'non-biting midges') usually dominates benthic communities in high altitudinal stream habitats, particularly in glacier-fed streams (Füreder et al. 1998, Lods-Crozet et al. 2001, Füreder 2009). Such alpine stream systems fed by glaciers are generally prone to environmental change in the near future, as most glaciers

retreat (Zemp et al. 2009). As most notable environmental changes (without additional direct human influences others than climate change) occur in high mountainous regions, long-term ecological research programs have begun to monitor also the interdisciplinary consequential effects of glacier retreat on alpine stream ecosystems (e.g. Füreder & Schöner 2013). One of such Long-term Socio Ecological Research programs (LTSER), a development of cross-disciplinary, long-term and place-based socio-ecological studies (Singh et al. 2013), has been conducted within the Matsch Valley, South Tyrol (Italy) since 2008. The Saldur stream, a permanent glacial alpine stream, drains this dry valley. Amongst others, alpine stream invertebrate communities are monitored and analyzed in regular time intervals to quantify and estimate ecological consequences of environmental changes in this headwater system. A comprehensive study analyzing the population dynamics of benthic macroinvertebrate communities within the glacial-melting season of two consecutive years is currently in preparation (Scotti et al., *unpublished*). However, no studies concerning benthic invertebrate population structures or the species pool comparing glacial and non-glacial systems of Matsch Valley have been reported so far.
To achieve this goal, a valuable dataset on alpine stream invertebrates in the Saldur stream and its tributaries has been collected. In particular, we analyzed the benthic communities from glacial and non-glacial streams in the Matsch Valley along an altitudinal gradient ranging from 2252 to 980 m a.s.l.. In demonstrating general trends of invertebrate taxa along the altitudinal gradient in this particular valley, we provide a fundamental basis for further studies and monitoring purposes.

Methods

Study area
Our investigation took place within the Matsch Valley, a watershed with a drainage area of about 100 km^2, enclosed within the upper Vinschgau Valley (South Tyrol, Italy) (Fig. 1). This valley is characterized by a relatively dry climate with a yearly average rainfall of 550 mm (period 1970-2000; source: Hydrographic Office, South Tyrol). The Matsch Valley is a quite sensible region due its continental climate. Thus, it can be considered as an "early warning" region, because the dry habitats already present are likely to extend to wider regions during the progress of climate change. The

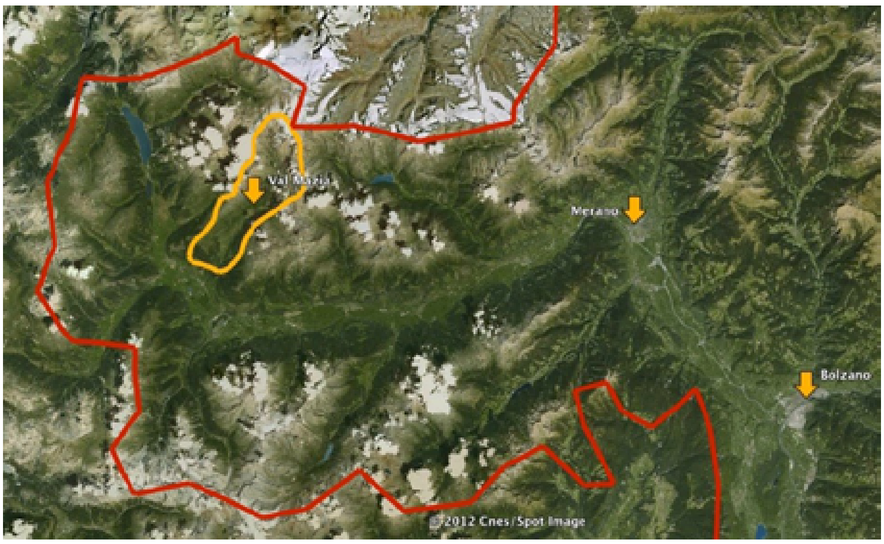


Figure 1. Matsch Valley ("Val Mazia") with the Saldur catchment, located in the north of Vinschgau Valley.

selected study sites belong to an LTSER-site (Long Term Socio-Ecological Research; http://lter.eurac.edu) and are intensively monitored since 2014. Several environmental parameters such as precipitation, air temperature, humidity, wind speed, solar shortwave and photosynthesis active radiation, leaf area index, soil moisture, snow depth and soil temperatures are continuously measured at 13 climatic stations within the catchment since 2009.

The Matsch glacier "Weißkugel" still covers a significant part of the catchment (2.2 km^2), but retreated tangibly, mostly at the beginning of last centuries (Galos & Kaser 2014). The Saldur stream drains the valley and originates from glacial and non-glacial tributaries. The streamflow is dominated by the glacier dynamics (a water gauge is present at ca. 6 km from the source). A seasonal threshold of maximum discharge during the summer period could be observed. Outliers are caused by storm events with increased precipitation and thus increased surface runoff. In relation to daily discharge peaks in summer, the ones in autumn are decreased because of lower air temperatures. Daily amplitudes decrease along the season and nearly disappear in late autumn (Hydrographical Office Autonomous Province of Bolzano/Bozen).

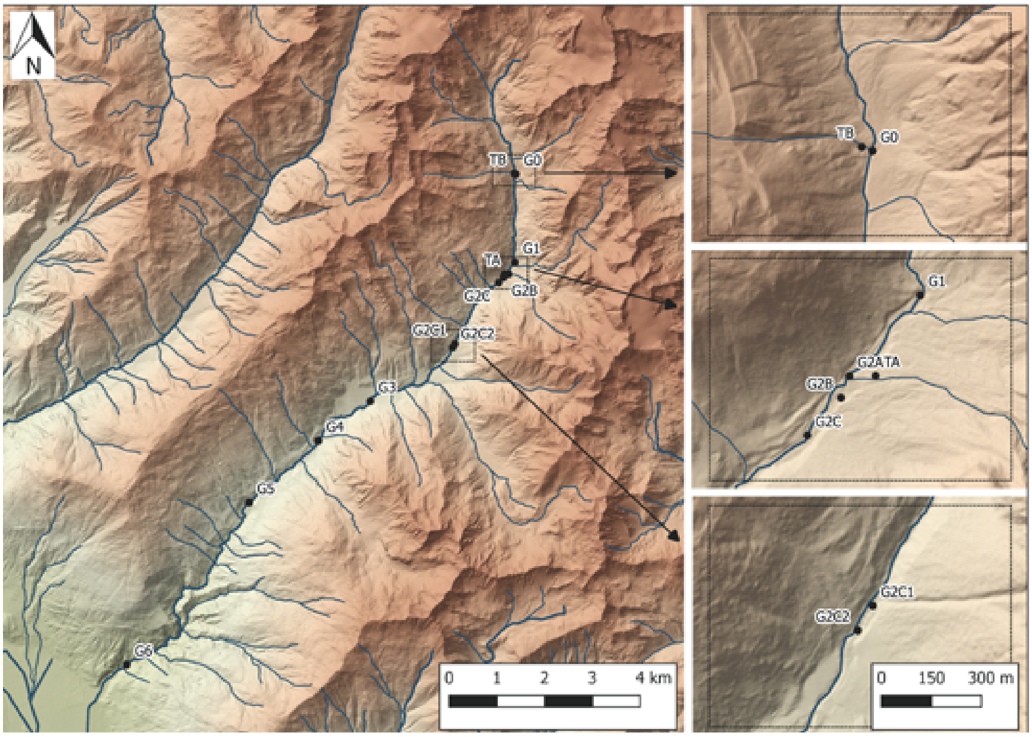


Figure 2. Sampled stream reaches of glacial and non-glacial (TA and TB) streams in the Matsch Valley (South Tyrol, Italy), along an altitudinal gradient ranging from 2252 to 980 m a.s.l.

To analyze the spatial distributional patterns of macroinvertebrates along the main water course and its tributaries, we selected sampling sites (Fig. 2) at increasing distances from the glacier in glacial (11 sites) and non-glacial tributaries (2 sites). The selected sites include glacial and non-glacial stream reaches, ranging from 2252 to 980 m a.s.l. (Fig. 2, Table 1).

Table 1. Site identification, site description and location as well as the corresponding elevation of each sampled glacial and non-glacial stream reaches.

SITE NAME	SITE DESCRIPTION	STREAM TYPE	LONGITUDE LATITUDE	ELEVATION (M A.S.L.)
G0	above tributary B	glacial	46.761235° N 10.703312° E	2243
TB	tributary B (non glacial)	non glacial	46.761345° N 10.702899° E	2252
G1	above tributary A	glacial	46.744591° N 10.702539° E	2044
TA	tributary A (non glacial)	non glacial	46.742444° N 10.700715° E	2024
G2A	above derivation and just below TA	glacial	46.742451° N 10.699685° E	2017
G2B	above sand trap	glacial	46.741871° N 10.699342° E	2010
G2C	below sand trap	glacial	46.740878° N 10.697979° E	1992
G2C1	above hydraulic control structures (Glieshof)	glacial	46.729503° N 10.685620° E	1864
G2C2	below hydraulic control structures (Glieshof)	glacial	46.728848° N 10.685008° E	1847
G3	above crossing SP	glacial	46.719060°N 10.662140°E	1726
G4	above Tumpaschin	glacial	46.711810°N 10.647640°E	1648
G5	above Matsch (Mühlhof)	glacial	46.700471°N 10.628339°E	1503
G6	above Schluderns	glacial	46.670382°N 10.593921°E	980

Sampling and taxa identification

From 25th to 27th June 2016 we took qualitative samples of multiple microhabitats at each site using a Surber sampler with a mesh size of 500 µm. In total, we sampled 13 sites (Fig. 2). We sorted living organisms from the rest of the samples (detritus, other organic matter, solid rocks, etc.) immediately in the field and stored them in 75% ethanol. The organisms were identified in laboratories at the University of Innsbruck, the Eurac Research in Bozen, the ARGE Limnologie in Innsbruck and the Biological Laboratory in Leifers by different experts using appropriate keys (e.g. Ferrarese & Rossaro 1981, Horn et al. 1993, Lechthaler & Car 2005, Lechthaler & Stockinger 2005, Graf & Schmidt-Kloiber 2008, Timm 2009, Waringer & Graf 2011, Eiseler 2012, Lubini et al. 2012, Faasch 2013, Van Haaren & Soors 2013, Bauernfeind & Lechtaler 2014, Rossaro & Lencioni 2015) using a stereomicroscope and a transmitted light microscope with a magnification up to 400-x.

Data analysis

We generated a taxa list with presence/absence data per stream reach. Simple linear models were used to describe the relationships of taxa number of all invertebrates with the independent variable altitude in a) all stream types and b) the glacier-fed Saldur stream and absolute and relative taxa numbers as dependent variables. For that, a significance level of 5% was defined for F-tests, which were used to verify if the respective model provides a better fit than the intercept-only model. We compared the absolute and relative species number of Chironomidae and other taxa in different stream types (glacial and non-glacial), which were located between 2010 and 2252 m a.s.l., using t-tests. Furthermore, we calculated the relative number of chironomid taxa in respect to the total taxa richness. The analyses were performed in R (version 3.3.2).

Results

Numbers of invertebrate taxa

Our dataset, investigating the taxa occurring in 13 different sites, consists of 302 positive entries, belonging to 94 different taxa (Table 2). In total 80 distinct taxa (genera, species-groups and species) were considered in statistical analysis. The residual 14 taxa were not included in the analysis due to taxonomic difficulties and/or incomplete bodies. According to previous work (e.g. Alber et al. 2015, Lösch et al. 2016), five new species for South Tyrol were found: *Micropterna lateralis* (Trichoptera), *Stenophylax vibex* (Trichoptera), *Rhyacophila producta* (Trichoptera), *Prosimulium tomosvaryi* (Diptera), and *Simulium* (*Obuchovia*) *galloprovinciale* (Diptera) (Table 2).

Table 2. Identified taxa and occurrence at the surveyed stream sites in Matsch Valley. Capitalized names denote families. Grey colored taxa (e.g. *Stylodrilus* sp.) were not used for analyses. Taxa names with grey background (e.g. *Micropterna lateralis*) are new records for the province South Tyrol.

NR.	TAXA	G0	TB	G1	TA	G2A	G2B	G2C	G2C2	G2C1	G3	G4	G5	G6
	TURBELLARIA													
1	*Crenobia alpina*		X		X						X			
	ENCHYTRAEIDAE													
2	*Cognettia* sp.		X		X		X				X			
3	*Fridericia* sp.		X								X			
4	*Henlea* sp.											X		
5	*Mesenchytraeus armatus*											X		
	LUMBRICIDAE													
6	*Lumbricidae* Gen. sp.												X	
	LUMBRICULIDAE													
7	*Stylodrilus heringianus*									X	X			
8	*Stylodrilus* sp.										X			
	ACARI - HYDRACHNIDIA (Wassermilben)													
	LEBERTIIDAE													
9	*Lebertia* sp.		X											
	BAETIDAE													
10	*Baetis alpinus*	X	X	X	X	X	X	X		X	X	X		
11	*Baetis* juv.sp.			X							X	X		
	HEPTAGENIIDAE													
12	*Ecdyonurus* sp. juv.										X		X	
13	*Epeorus alpicola*										X	X		
14	*Rhithrogena degrangei*											X		
15	*Rhithrogena loyolaea*		X								X	X		
16	*Rhithrogena nivata*										X	X		
17	*Rhithrogena* sp.										X		X	
	CHLOROPERLIDAE													
18	*Chloroperla susemicheli*										X			
19	*Chloroperlidae* Gen.sp.											X		
	LEUCTRIDAE													
20	*Leuctra rosinae*					X								
21	*Leuctra* sp.	X	X	X	X	X	X	X	X	X	X	X	X	X
	NEMOURIDAE													
22	*Nemoura mortoni*	X			X	X		X	X	X	X	X		X

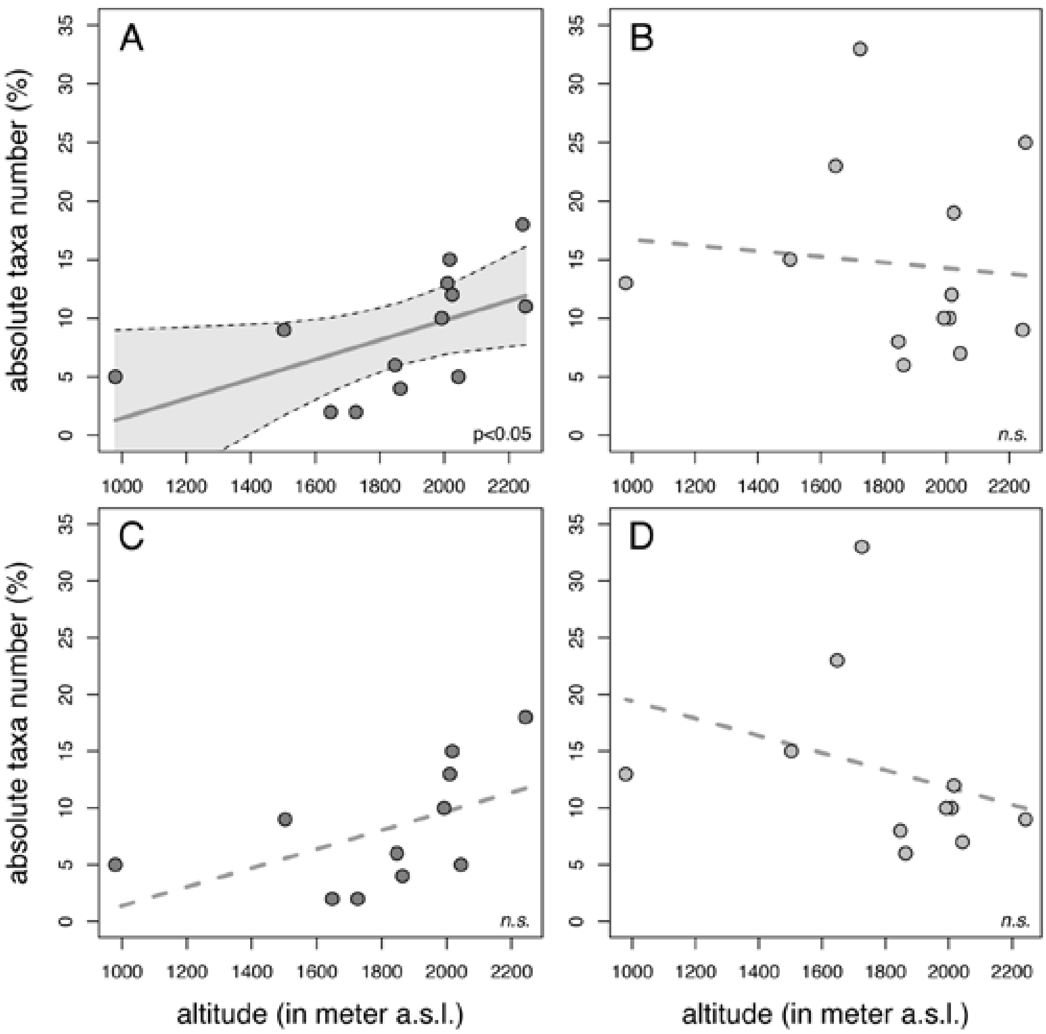
NR.	TAXA	G0	TB	G1	TA	G2A	G2B	G2C	G2C2	G2C1	G3	G4	G5	G6
23	*Nemoura* sp.	X										X		
24	*Protonemura brevistyla*					X		X					X	
25	*Protonemura* juv.					X		X					X	X
26	*Protonemura nitida*												X	X
27	*Protonemura* sp.	X	X	X	X	X	X		X	X	X	X	X	
	PERLODIDAE													
28	*Dictyogenus alpinus*										X	X		
29	*Dictyogenus fontium*		X		X									
30	*Isoperla* sp.		X		X						X	X	X	
	ELMIDAE													
31	*Elmis latreillei*											X		
	HYDRAENIDAE													
32	*Hydraena lapidicola*													X
33	*Hydraena* sp.													X
	LIMNEPHILIDAE													
34	*Allogamus auricollis*													X
35	*Cryptothrix nebulicola*		X											
36	*Drusus discolor*		X		X			X			X			
37	*Drusus melanchaetes*						X							
38	*Drusus* sp.				X						X			
39	*Drusinae* Gen. Sp.					X								
40	*Halesus rubricollis*										X			
41	*Micropterna lateralis*											X	X	
42	*Stenophylax vibex*													X
43	*Limnephilidae* Gen. sp.	X	X		X	X	X	X						
	RHYACOPHILIDAE													
44	*Rhyacophila intermedia*		X		X	X	X							
45	*Rhyacophila producta*				X									
46	*Rhyacophila torrentium*										X	X	X	X
47	*Rhyacophila* sp.						X	X					X	
	SERICOSTOMATIDAE													
48	*Sericostoma personatum*										X			
	DIPTERA													
	BLEPHARICERIDAE													
49	*Blepharicera fasciata*				X				X					
50	*Liponeura cinarescens*		X	X		X						X		
	CERATOPOGONIDAE													
51	*Ceratopogonidae* Gen. sp.										X			
	CHIRONOMIDAE													
52	*Brillia bifida*				X		X			X				
53	*Chaetocladius piger*-Gr.	X			X								X	
54	*Diamesa cinerella*-Gr.	X			X	X	X	X		X			X	
55	*Diamesa dampfi*-Gr.		X								X			
56	*Diamesa insignipes*	X												
57	*Diamesa latitarsis*-Gr.	X	X	X	X	X	X	X		X			X	X
58	*Diamesa (Diamesa) steinboecki*	X		X	X	X	X	X						
59	*Diamesa zernyi*-Gr.	X	X	X	X	X	X	X	X	X	X		X	

NR.	TAXA	G0	TB	G1	TA	G2A	G2B	G2C	G2C2	G2C1	G3	G4	G5	G6
60	*Diamesa* sp.	X		X			X							
61	*Eukiefferiella brevicalcar*	X				X								X
62	*Eukiefferiella fittkaui/minor*	X	X		X	X	X	X	X	X		X	X	X
63	*Eukiefferiella fuldensis*	X	X			X	X	X						
64	*Eukiefferiella* sp.	X												
65	*Micropsectra atrofasciata* aggr.	X	X		X	X	X							
66	*Orthocladius (Euorthocladius) rivicola*	X												
67	*Orthocladius (Euorthocladius) luteipes*	X				X	X					X	X	X
68	*Orthocladius (Mesorthocladius) frigidus*	X	X		X	X		X					X	X
69	*Orthocladius (Orthocladius)* sp.		X		X									
70	*Parametriocnemus stylatus*					X	X							
71	*Paraphaenocladius* sp.					X								
72	*Paratrichocladius nivalis*	X	X											
73	*Paratrichocladius rufiventris*	X											X	
74	*Pseudodiamesa branickii*		X			X		X	X					
75	*Pseudokiefferiella parva*	X	X	X	X	X	X	X	X	X			X	
76	*Stilocladius montanus*						X							
77	*Tvetenia calvescens*				X	X		X						
	DIXIDAE													
78	*Dixa puberula*		X											
	EMPIDIDAE													
79	*Hemerodromia* sp.		X								X			
	LIMONIIDAE													
80	*Molophilus* sp.									X				X
81	*Rhypholophus* sp.									X				
82	*Limoniidae* Gen. sp.							X	X					
	PEDICIIDAE													
83	*Dicranota* sp.	X	X	X	X		X	X			X	X	X	X
	PSYCHODIDAE													
84	*Berdeniella/Bazarella* sp.		X								X	X	X	
	SIMULIIDAE													
85	*Prosimulium (Prosimulium) hirtipes*		X		X						X			
86	*Prosimulium (Prosimulium) latimucro*	X		X						X				
87	*Prosimulium (Prosimulium) rufipes*		X		X		X		X		X	X		
88	*Prosimulium (Prosimulium) tomosvaryi*		X								X			
89	*Prosimulium* sp.		X		X						X		X	
90	*Simuliidae* Gen. Sp.										X			X
91	*Simulium (Obuchovia) galloprovinciale*													X
92	*Simulium* sp.											X		
	THAUMALEIDAE													
93	*Thaumaleidae* Gen. sp.	X	X		X									
	TIPULIDAE													
94	*Tipula (Savtshenkia)* sp.		X			X					X			

Relationship of invertebrate taxa and altitude

On average, we found 23 ± 8 taxa per stream reach. However, the total number of taxa found per site was not significantly related to altitude (F-test, $p>0.05$) (Fig. 3 A). In addition to species number, even the richness of invertebrate families (e.g. Baetidae, Chironomidae, etc.) did not increase with decreasing elevation (F-test, $p>0.05$). At the highest stream site, Chironomidae represented 49% of all taxa. However, this dipteran family accounted for only a minor fraction (16%) at the lowest location (980 m a.s.l.). Across all sampled streams (main watercourse and two tributaries), chironomid taxa accounted for 37% of all sampled taxa and were present in every sample. In contrast to the total taxa number (Fig. 3 B and D), the number of chironomid taxa increased significantly along the gradient of altitude ($F=5.03$, $p<0.05$) with a mean rate of 0.8 taxa per 100 meters (Fig. 3 A). The same rate was observed in glacier-fed reaches (without the non-glacial sites), but this relationship was not significantly different from zero (Fig. 3 C).

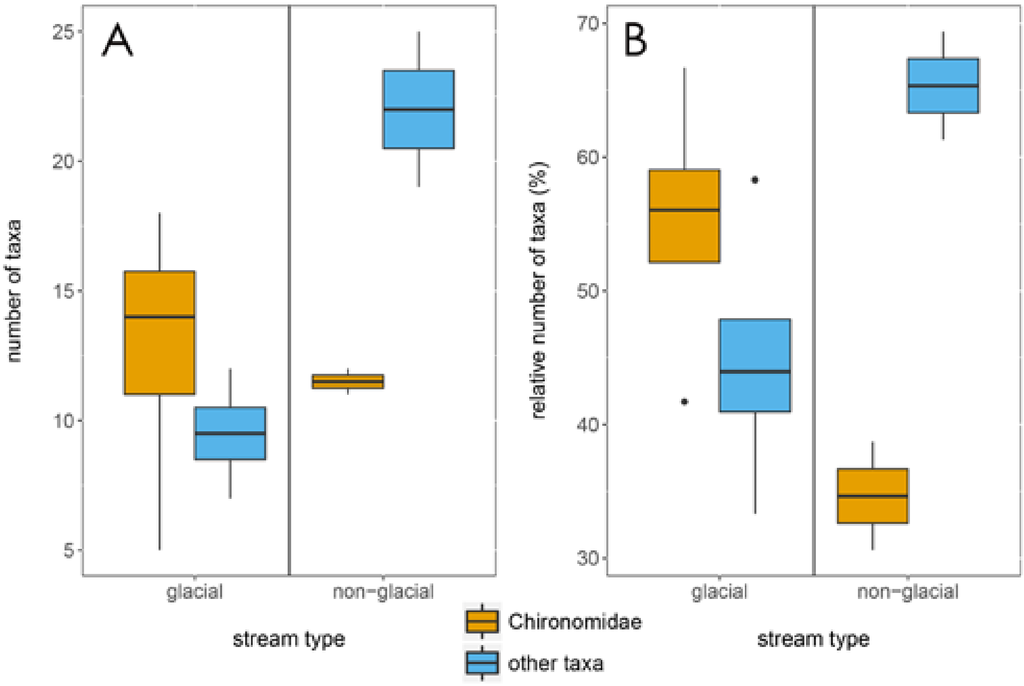
Figure 3. Relationships between altitude (in meters above sea level) and (A, C) chironomid taxa and (B, D) all invertebrate taxa in absolute numbers. A and B include all sampled reaches, C and D only glacier-fed stream reaches. Lines indicate significant (solid) and non-significant (dashed) linear relationships, dotted lines indicate 95% confidence intervals of the significant relationship.



Stream type specific assemblage structures

In glacial and non-glacial streams above 2010 m a.s.l. we found non-significant differences (t-test, p=0.65) of taxa richness. Glacial stream reaches (i.e. sampling sites on Saldur stream) harbored 22 ±7 taxa (mean ± standard deviation) and most of them belonged to the family Chironomidae. In the non-glacial streams, 34 ± 4 taxa were identified, of which the majority did not belong to Chironomidae (Fig. 4 A). Thus, while chironomid taxa accounted for 56 ± 10% of all taxa in glacial stream reaches, they were underrepresented in non-glacial streams with only 35 ± 6% of all taxa. Thus, the relative contribution of Chironomidae taxa to the structure of the benthic community is significantly different (t-test, p=0.03) in both stream types (Fig. 4 B).

Figure 4. Absolute (A) and relative (B) taxa richness of chironomids (Chironomidae) and other groups (other taxa) in glacial (n=4) and non-glacial (n=2) streams at similar altitudes (between 2010 and 2252 m a.s.l.). Lines inside the boxes denote the median of the data, boxes frame the central 50% of the data.



Discussion

Recent studies (e.g. Milner et al. 2001, Füreder 2012) recorded a general increase of invertebrate taxa colonizing glacier-fed streams downstream with increasing distance from the glacier. As altitude usually decreases with increasing distance from the glacier, we used this factor as proxy for distance to the glacier. However, based on this dataset from Matsch Valley, and although we started sampling >2 km downstream from the glacier, we can argue that the conceptual assumption from Milner et al. (2001) might not apply for all glacial catchments in the same way, as no significant relationship was found between taxa richness of invertebrates in the glacier-fed Saldur stream and altitude in the present work. However, as this survey was limited in seasonal and spatial replication, did not involve water temperature (as used for the conceptual model in Milner et al. 2001) or stream reaches close to the glacier, further samplings using more replicates are encouraged to study the relationship of environmental conditions and the response, occurrence and structure of benthic invertebrate communities in Matsch Valley.

Taxa richness of invertebrate communities in the glacier-fed Saldur stream was found in similar numbers as in other glacier-fed streams in the Alps (Castella et al. 2001). This is also the case with the composition of the invertebrate assemblages, which are in line with recorded community structures in European glacier-fed streams (Lods-Crozet et al. 2001), with a clear dominance of Chironomidae in terms of abundance. We can conclude that, in addition to the known numerical dominance of chironomids in alpine headwaters (e.g. Füreder 1999, Füreder et al. 2001, Lods-Crozet et al. 2001, Niedrist & Füreder 2016), this dipteran family might also be the most diverse and taxa-rich insect family in high-altitudinal glacially influenced headwater streams. Furthermore, species belonging to this family seem to be well distributed on the streambed, as we found chironomids in every sample from the Matsch Valley. Thus, a potential relationship of the relative species number of Chironomidae and the abiotic environment in glacier-fed streams, which is under constant transformation during glacial recession, should be verified in a more confound study. As the chironomid subfamily Diamesinae is known to dominate in glacier-fed streams in the Alps (e.g. Füreder 1998, 1999, Füreder et al. 2001, Lods-Crozet et al. 2001, Niedrist 2014), the relative species number of this subfamily should be used for such an approach.

The higher taxa richness found in non-glacial streams is in line with previous studies (e.g. Füreder et al. 2001, Niedrist & Füreder 2016), showing that stable and clear conditions allow more species to colonize all stream habitats, which generally leads to a higher diversity (Lencioni & Spitale 2015). In this sense, alpine headwater streams can be defined as real hotspots of biodiversity. This can also be confirmed by the discovery of five new species for South Tyrol.

Generally, invertebrate communities seem to be considerably different in streams with and without glacial impact in the Matsch Valley, particularly the relative contribution of chironomid taxa to the total invertebrate community differs between glacial and non-glacial streams. Thus, as chironomid taxa seem to be bound to the influence of glaciers in alpine streams, monitoring activities should include selected metrics of invertebrate communities in the glacier-fed Saldur stream (e.g. taxa number of chironomids in relation to all present taxa), which then allows the estimation of consequences caused by glacier-retreat on the subsequent ecosystem glacier-fed stream.

Riassunto

Variabilità degli invertebrati acquatici nei torrenti glaciali e non-glaciali della Val Mazia (Alto Adige, Italia)

Le comunitá di macroinvertebrati acquatici legati agli ambienti glaciali alpini sono strettamente condizionate dal ritiro dei ghiacciai. È quindi ipotizzabile che in un futuro prossimo la struttura di queste comunitá potrá esserne fortemente alterata. Dal 2014 in Val Mazia la struttura della comunitá bentonica aquatica è regolarmente monitorata, nonostante non fossero ancora conosciuti i cambiamenti a livello di specie lungo l'asta principale del torrente glaciale Rio Saldura e dei tributari non glaciali. Questo studio analizza in maniera qualitativa la comunitá bentonica di questi due ambienti acquatici, considerando un transetto altitudinale compreso tra 2252 e 980 m s.l.m. e fornendo una importante base di dati per il successivo monitoraggio a lungo termine del Rio Saldura. In particolare, la presenza di taxa riconducibili alla famiglia dei Chironomidae è maggiore, in termini assoluti, nei tratti di corsi d'acqua localizzati a quote piú alte. Inoltre, i chironomidi sono i macroinvertebrati maggiormente rappresentati nei tratti glaciali, mentre la loro presenza non è ugualmente consistente nei tratti non glaciali. In conclusione, il rapporto fra chironomidi (piú specificatamente della sottofamiglia Diamesinae, maggiormente adattata alle condizioni ambientali che si trovano in prossimitá dei ghiacciai) e taxa complessivi rinvenuti potrebbe valere come un buon indicatore per monitorare i cambiamenti ambientali dovuti al ritiro dei ghiacciai e analizzare gli effetti sulle comunitá bentoniche dei fiumi alpini.

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